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Evaluation of Peak Shifting and Saving Energy of Ice Storage Air Conditioning System in Iran

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Abstract- *Thermal energy storage (TES) system has been introduced as a practical facility for shifting load from peak hours to off-peak hours. Because of different energy consumption during day and night, peak and off peak period is created on load curve. Ice storage technology which is a kind of TES system, is implemented in different points of the world with the purpose of solving load shifting problem. The basic process of this technology is storing energy in the ice during off-peak hours, utilizing an air conditioning unit in which the stored energy will be utilized during day. Utilization of ice storage system is a good solution for optimizing consumption of gas and electrical energy, which will be effective in urban pollution reduction. This paper aims to introduce load shifting problem and the implemented procedures to overcome this problem from the past, analyzing ice storage system as a solution to this problem. Moreover, feasibility of the ice storage technology on a case study in Iran is discussed to show the performance and efficiency of the technology. The obtained results for the case study show that by utilizing ice storage system the consumption and the paid cost will be reduced with respect to conventional system.*

Keyword: Load shifting, Thermal energy storage, Ice storage system, Air conditioning unit.

NOMENCLATURE

t	Index for time interval
i	Index for different pumps used in ice storage system
j	Index for different cooling tower used in ice storage system
k	Index for different chiller used in ice storage system
Ch	Set of different type of chiller systems
Pu	Set of different type of pumps
CT	Set of different type of cooling towers
$\lambda(t)$	Forecasted electricity price in time period
T	Studied time period(24 hour)
$P_c(t,k)$	Power consumption of k-th screw type chiller and auxiliary equipment in time period t
$\eta(t)$	The chiller efficiency related to ambient temperature
$P_{pump}(i)$	Power consumption of i-th pump.
$P_{c,tower}(j)$	Power consumption of j-th cooling tower
COP_n	Nominal performance coefficient of chiller
$P_{c,n}(k)$	Nominal power consumption of k-th chiller
$R_{cap}(t)$	Full load chilling capacity ratio
$R_{chiller}(t)$	Full load power consumption ratio
$T_{ch,n}$	Nominal chilled water outlet temperature
$T_{cool,n}$	Nominal cooling water inlet temperature
$T_{ch}(t)$	Actual chilled water outlet temperature
$T_{cool}(t)$	Actual cooling water inlet temperatur

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1. INTRODUCTION

Considering the rapid growth of population of the world and industries development, energy consumption is increased in past centuries with an annual increment ratio of 2.3% [1]. Buildings are numerated as one of the most energy consumption cases, for which heating, ventilation, and air conditioning systems are introduced as the most energy consumption cases [2]. There are various cold thermal energy facilities for load shifting control, including building thermal mass (BTM), thermal energy storage system (TES), and phase change material (PCM). For peak demand cost reduction, the peak demand should be reduced, which is defined as peak demand management.

Periods with a lower electricity price and higher price are denoted as “off-peak period” and “on-peak period”, respectively [3]. An annual saving of $10-$15 billion can be attained for US market by considering peak demand management [4]. Three different objectives can be considered for load shifting, including: a) the operating cost minimization, b) the peak demand cost minimization, and c) the energy cost minimization [5]. Demand response programs (DRPs) are introduced as one of practical solution to shift loads from on peak hours to off peak hours, which plays a significant role in cost minimization [6]. As an instance, direct load control (DLC) is an incentive-based DRP, which is an effective solution for reducing the curtailment of load by permitting the system operators to curtail the consumers load in peak hours [7].

A practical idea for saving energy in buildings is TES system, which is considered as an attractive subject in this area [8]. This system is introduced as one of most important advanced energy technologies, which recently has been widely paid attention to as a solution for shifting from on-peak hours to off-peak hours. Three main types of TES exist including sensible (water and rock), latent (water/ ice and salt hydrates), and thermochemical (inorganic substances). Some main factors are utilized as definition for selecting the TES system type such as required storage period, economic viability, operating condition, etc. [9]. A balanced energy demand between on-peak and off-peak hours can be achieved by implementing TES systems. TES systems have a capability of storing the summer heat for heating an area during the winter and storing the winter cool for cooling an area during the summer. As an instance of TES systems, storing of ice in the summer during off peak hours for space cooling in subsequent peak hours can be accomplished [10]. Utilization of a stored cold energy in a storage medium is introduced as a practical procedure for air conditioning purposes in buildings. Such technology shifts electrical load from on-peak hours to off-peak hours which helps to reduce or eliminate peak demand [11]. As a result, the stability of the electrical load and reduction of consumers’ power bill can be accessed.

Ice storage air conditioner system that uses natural flowing benefits can be operate as cooling / heating mechanism in the summer or winter and reduce energy consumption of home and office. The most real world applications of ice storage include industry applications where the sudden and high cooling is needed, such as milk processing industry, where they need to cool down the whole quantity of milk in less than one hour. Furthermore, the ice storage air conditioning system is designed at the schools such as Hornell high school and BJM elementary school.

The most important advantages of such devices are peak shifting from on-peak consumption period to off-peak consumption period. It should be noted that peak demand is defined as the maximum load demand over a determined time interval [12]. The new technology of ice storage is a quantum leap in storing energy and increasing the usage of energy converters. Storing of chemical energy carriers like oil, gas, coal, and others without much cost is possible, but storing electrical energy generally is very difficult and costly. Fossil fuels cost increment and environmental anxiety are motivated TES for space heating and cooling of buildings as an important challenge [13]. As reported in [14], the storage-led operating strategy is better than chiller-led operating strategy considering the peak-valley price of tariff. The technology of ice storage is a kind of distributed energy storage system, which can be counted as an important element of demand side management [15].

Several strategies on optimal operation and high efficiency achievement of ice storage system are studied in recent years. Authors introduced a near optimal strategy, a weight priority method in [16] which has a simple usage and good economic performance. An adaptive simulated annealing genetic algorithm (ASAGA) is introduced in [15] for optimizing the ice storage air conditioning system. Dynamic characteristic of a constant proportion ice ball storage system is determined in [17]. A new method for improving heat transfer between water and refrigerant plus making water freezing uniformly is proposed in [18]. The most cost saving from implementing demand side management optimization controller to an ice storage system whit real time electricity price are studied in [19]. In Ref [20, 21], energy, exergy, economic and environmental aspects of ice storage system with using multi-objective optimization are analyzed. Research on importance of simultaneous utilization of both storage media in the context of optimal control is presented in [22]; however, shifting cooling loads and active TES systems have been employed separately in the past. Reference [23] is introduced smart appliances and an energy storage unit with conversion losses for solving load shifting problem in a household. An event driver model predictive control (MPC) method is utilized in this reference. Moreover, two different scenarios including optimization of economic saving in case of TOU tariffs and demand side management have been introduced to handle by the controller. The main purpose of [24] is to improve load management efficiency by presenting a novel optimization procedure, which considers both economic efficiency and load shape based on economy theory. A review on latent heat storage and recent studies on PCMs is provided in [25], which focused on PCM materials, encapsulation and applications. In [26], the authors utilized the binary integer programming for the solution of the distribution system reconfiguration and providing the load balance among distribution main transformers during the summer peak load.

Iran has a warm climate, so there is a lot of air conditioning demand, which has a considerable impact in causing peak problems in summer. In the last 25 years, urban patterns growth has made large population centers where the power network could not deliver demand sufficiently. Variations of electrical energy consumption during the day and night, cause different prices for peak and off peak periods of energy utilization [27]. The main goal of this paper is to introduce ice storage technology as a solution tool for solving load shifting problem.

- The contributions of this research study can be summarized as the following:
- A practical solution is proposed for solving the load peak in summer in Iran
- Ice storage method is introduced in this research study to minimize the power system production cost
- Ice storage method is a practical solution to shift loads from on peak hours to off peak hours in summer
- The payment of consumer to power load will be increased by using this approach

The remainder of this paper is organized as follows. In section 2, ice storage conditioning system is discussed. A case study is proposed in section 3 for evaluation the proposed storage strategy. Finally, the paper is concluded in section 4.

2. ICE STORAGE AIR CONDITIONING SYSTEM

A conventional air conditioner is a full energy consumed machine. The refrigeration cycle of a conventional air conditioner is typically driven by an electric motor, which gets hotter during the day and the efficient of such motor decreases and it draws more energy and provides less cooling.

The ice storage air conditioner technology provides an opportunity for businesses to facilitate their cooling requirements, and receiving the advantage of using lower off-peak energy prices at night. In addition, such technology helps energy utilities to make consumers shifting their air-conditioning loads to off- peak hours.

An innovational technology which provides an energy storage system and enables customers to use air conditioning units in off-peak hours, is named the ice bear.

The ice bear uses a well-known technology of air conditioner for making a block of ice. Different levels of ice bear process for cooling include: first, condensing at night when environment temperatures are cooler. The condenser works steadily, which uses energy at the off-peak evening times, and stores all that energy as ice. The created ice does not cool the building. It has been made to condense the refrigerant. The ice bear is necessary for an ice condensing unit. Then, when a building needs for cooling during the day, refrigerant pumps up into an evaporator coil by an electric motor and it converts from a liquid to a vapor in the evaporator. In a conventional air conditioner, the heat in the vapor is then released through a full energy consumed electrical condenser. But the ice bear comes back the refrigerant instead through the block of ice, re-condensing the vapor into a liquid, and consumes less amounts of electricity at the same time.

The new technology of ice works according stored energy in the ice because of large heat of solidification for ice and large heat of fusion for water, one metric ton of water (one cubic meter) can store 334 mega joules (MJ) (317,000 BTU) of energy, equivalent to 93 kWh (26.4 ton-hours). The important case in this technology is using of ice at the melting point which the ambient temperature does not change, but relatively large energy can be extracted and stored from ice. When ice melts, much energy can be obtained and when water freezes much energy will be loosed and turns to ice. The technology is based on water natural ability storage for a relatively high level of thermal energy. Ice storage technology has wide usage on air conditioner systems. This system has been utilized in several states of America as the national master plan. Environmental advantages have introduced as one of the significant benefits of the ice storage scheme. The seasonal and daily energy consumption for cooling/heating based on cold/heat instrument technology is the source of troubles in serving energy. The accumulation of conventional technologies appears traffic and creates new problems in energy generation. The systems which depend on the natural transients such as ice storage can solve disadvantages of modern consumption and reduce energy consumption when traffic of energy consumption is high. Using ice storage approach, the air cooling device can be very effective, because these devices simultaneously cool the ambient and store cold at night when the temperature is suitable. The using of this process for cooling the residential and industrial places during on peak consumption is very efficient. The system can be used for hot days with little change in structure of devise, the type of tank. Ice storage systems have important role in the optimization of gas and electricity consumptions and have been very effective in reducing urban pollution and removing its disadvantages. To summarize, the benefits of this storage system can be categorized as the following:

- Shifting the peak consumption from on-peak hours to off-peak hours.
- Decreasing the energy consumption and environmental pollutions.
- Improving social welfare by using the new air conditioner systems.

Using the off peak electricity and storing energy as ice and using that stored ice for cooling in peak times are the difference between conventional chillers and ice storage air conditioner one. The differences between conventional water chillers and ice storage ones are compared at the Table 1.

Table 1. Comparison of conventional water chillers and ice storage ones

Air conditioning type	Conventional water chiller	Ice storage chiller
Temperature difference of 10 °C	2.2 kg of chilled water can store 19 kJ of thermal energy	2.2 kg of ice can store 178 kJ
Chilled water supplied temperature	1.1 to 1.7 °C	4 to 7 °C
Storage capacity	1	0.12
Chiller efficiency	5-6 COP	2.7-4 COP

Every ice storage air conditioning system consists of ice storage tank, cooling tower, chiller and auxiliary equipment shown in Fig 1. Chiller is the main power consumption component which ambient temperature affect the efficiency of chiller.

The power consumption models of such systems are established from manufacture’s data. The total cost of power consumption of ice storage air conditioning system is defined as below:

$$\text{total cost} = \sum_{t=1}^{T} \lambda(t) \times \left(\sum_{k \in Ch} P_c(t,k) + \sum_{i \in Pu} P_{pump}(i) + \sum_{j \in CT} P_{c,tower}(j) \right) \quad (1)$$

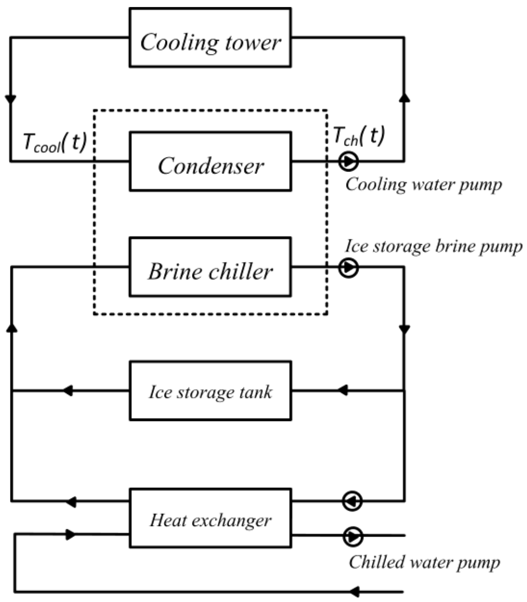

Fig 1. Ice storage air conditioning system

where $\lambda(t)$ is the forecasted electricity price in time period and $P_c(t,k)$ defines the power consumption of k-th screw type chiller and auxiliary equipment in time period t. $P_{pump}(i)$ states the power consumption of i-th pump which is calculated from pump electro motor and $P_{c,tower}(j)$ defines the power consumption of j-th cooling tower which is calculated from fan motor.

The power consumption of conventional chiller can be obtained from manufacture's data. Because of difference between manufacture standard temperature and ambient temperature that chiller is installed or changing in cooling load demand, chiller may be not operated under standard condition. So, the power consumption of chiller under the installed condition which is under influence of ambient temperature can be calculated as below:

$$P_c(t,k) = P_{c,n}(k) \times \eta(t) \tag{2}$$

$$\eta(t) = \frac{1}{COP_n} \times R_{cap}(t) \times R_{pow}(t) \tag{3}$$

In Eq. 2, $P_{c,n}(k)$ is nominal power consumption of *k*-th chiller and $\eta(t)$ is chiller efficiency related to ambient temperature. In Eq. (3), COP_n is nominal performance coefficient of chiller. $R_{cap}(t)$ and $R_{chiller}(t)$ are full load chilling capacity and full load power consumption ratios, respectively. The mathematical equation for calculating $R_{cap}(t)$ and $R_{chiller}(t)$ are determined from curve fitting of manufacture's data as below:

$$\begin{aligned} R_{cap}(t) = a_0 &+ a_1\Delta T_1(t) + a_2\Delta T_1^2(t) \\ &+ a_3\Delta T_2(t) + a_4\Delta T_2^2(t) \\ &+ a_5\Delta T_1(t)\cdot\Delta T_2(t) \\ &+ a_6\Delta T_1^2(t)\cdot\Delta T_2^2(t) \end{aligned} \tag{4}$$

$$\begin{aligned} R_{pow}(t) = b_0 &+ b_1\Delta T_1(t) + b_2\Delta T_1^2(t) \\ &+ b_3\Delta T_2(t) + b_4\Delta T_2^2(t) \\ &+ b_5\Delta T_1(t)\cdot\Delta T_2(t) \\ &+ b_6\Delta T_1^2(t)\cdot\Delta T_2^2(t) \end{aligned} \tag{5}$$

$$\Delta T_1(t) = T_{ch,n} - T_{ch}(t) \tag{6}$$

$$\Delta T_2(t) = T_{cool,n} - T_{cool}(t) \tag{7}$$

Where, $T_{ch,n}$ and $T_{cool,n}$ are the nominal chilled water outlet temperature and the nominal cooling water inlet temperature, respectively. $T_{ch}(t)$ is the actual chilled water outlet temperature and $T_{cool}(t)$ is the actual cooling water inlet temperature depicted in Fig 1. In Eqs. (4) and (5), $\Delta T_1(t)$ and $\Delta T_2(t)$ are obtained from standard operating conditions.

3. CASE STUDY

The main problem of business is dependence of them on their air conditioning system. According to statistics, air conditioning system is responsible for more than of 24 percent of peak power during summer as shown in Fig. 2. The peak demand problem can be solved by reducing customers' air conditioning demand and shifting it to off-peak hours.

The test system used for comparing the benefits of decreasing electricity cost and peak shaving is a commercial building complex integrating a hotel, office rooms, council chamber and other recreation rooms. The total building area is 52000 m^2 [28]. The ice storage air conditioning system used for this building include components such as condenser water pump, chilled water pump, ice water pump air agitation pump and cooling tower that presented in Table 2.

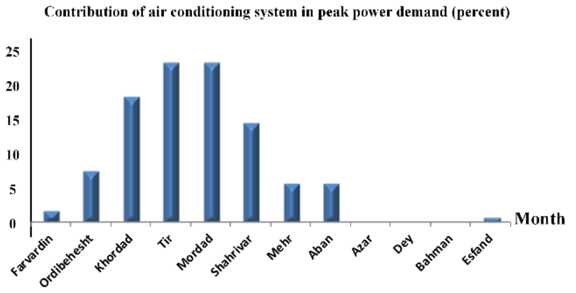

Fig. 2. Contribution of air conditioning system in peak power demand.

External-melt ice storage with two conventional chillers is studied as ice storage air conditioning system in this paper. The different type of pumps and cooling towers used in ice storage system during operation times, are stated in Table 2. The coefficients obtained from manufacture's data curve for calculating the power consumption of chiller are brought in Table 3.

Table 2. Ice storage system components

Type	Number	Power consumption(kW)
Condenser water pump	2	252
Chilled water pump	4	189
Ice water pump	2	168
Air agitation pump	2	67
Cooling tower	4	252

Table 3. Coefficients used in equations obtained from manufacture's data

coefficient	Amount	coefficient	Amount
a_0	0.9729593	b_0	1.1534788
a_1	-0.0364204	b_1	-0.016281
a_2	0.0004364	b_2	0.0000869
a_3	0.0122157	b_3	-0.020143
a_4	0.0000082	b_4	-0.000106
a_5	-0.0002919	b_5	0.0006727
a_6	-0.0000000	b_6	0.0000000

Energy consumption of air conditioning system in the summer that the utility is trying to preserve the load demand has a high contribution of demand in peak hours. Ice storage air conditioning system can help to shift the consumption of energy in on-peak hours to off-peak hours and help the electricity utility to follow and preserve the load demand. The other benefit of using ice storage system for storing energy and implementing it in the cooling system is saving energy with using of natural ice from frozen ice in winter and using them in summer. Developing natural ice storage air conditioning is in favor of economical society and can reduce total investment and operating cost and in Iran is suitable for using in the cold and mountainous areas. It suits Iran's geographical to put to use the cheap energy in night and balance electricity net load demand. The price of electricity during the hottest day of summer, 6 august of 2014, has been shown in Fig. 3 and the actual cooling load variation during of hottest day at summer has been shown in Fig. 4. The total energy consumed during 8:00-24:00 of typical hottest day is 38 457 kWh.

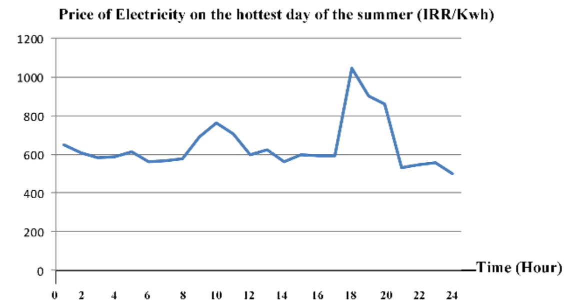

Fig. 3. Price of electricity during the hotest day of summer.

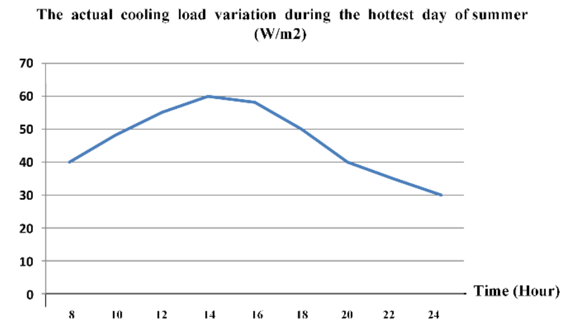

Fig. 4. The actual cooling load variation during the hottest day of summer.

The time of use electricity prices are presented in Table 4. The electricity cost comparison of energy consumption between conventional and ice storage using ice build chiller and ice storage using natural ice, air conditioning system is demonstrated in Table 5 and is resulted using the ice storage air conditioning system from view point of costumer decrease the payment of electricity bill.

Table 4. Variation of electricity price

Peak price (IRR/kW.h)	1048
Valley price (IRR/kW.h)	499
Difference between Peak and Valley price (IRR/kW.h)	549

Table 5. Comparison of daily energy consumption of conventional and ice storage air conditioning system.

Item of air conditioning system	Cost (IRR)
Conventional	2.676×10^{7}
Ice storage (using ice build chiller)	2.013×10^{7}
Ice storage (using natural ice)	1.338×10^{7}

In Fig. 5, the contribution of ice storage air conditioner in the actual load of air conditioner demand is depicted and showed that how much of peak load is produced from ice storage air conditioning demand. So, from the power system view point ice storage air conditioning system shift the peak loads to off peak load.

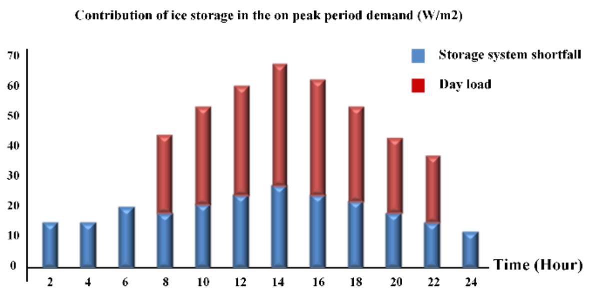

Fig. 5. Contribution of ice storage in the on peak period demand.

4. CONCLUSIONS

Ice storage air conditioning system can be widely used in buildings to shift loads from on-peak hours to off-peak hour. The other benefit of using ice storage air conditioning system is using the natural ice instead of condensing refrigerant and saving energy. Using of natural ice can reduce CO2 emission. In this paper, the implementation of ice storage air conditioning system in a commercial building has been studied. Such system helps to use energy in off-peak hours for condensing refrigerant and making ice, which is then used in on-peak periods to shift demand from on-peak hours to off-peak hours. The daily peak load shifting and daily cost minimization is obtained by using of ice storage air conditioning system. Additionally, ice storage system is able to minimize the power system production cost. As future study, the authors are working to stochastic modeling of cooling loads and price with implementing ice storage system to a micro-grid in presence of wind farm.

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